

Environmental Implications of Charcoal Production and Supply to Bonga Town: The Case of Kefa Zone, Southwest Ethiopia

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Abstract

Charcoal production is one of the major challenges for sustainability management of natural forest in Ethiopia. The study aimed to quantify the amount of charcoal produced and supplied from Bonga town surrounding districts and estimate its implications on the environment. Field surveys, household surveys, key informant interviews and focus group discussions were done to collect charcoal production and supply data in the study area. The result revealed that on average a total of about 499 and 60728 bags of charcoal supplied to Bonga town every day and annually from the five major inlet sites, respectively. On average, 15 tons/day and 5448.8 tons/year of charcoals supplied to Bonga from five inlet sites of Gimbo and Decha districts. The tops three preferred wood tree species for charcoal production are *Millettia ferruginea* (Hochst.) Baker, *Ehretum cymosa* Thonn and *Vepris daniellii* (pichi-Sernolli) Kokwaro, of which two are endemic to Ethiopia. About 1,716,372 m³ of green wood, 1,492,497.4 m³ of dry wood and 71,071 trees were required on yearly basis from forest to produce and supply to Bonga town. Furthermore, 14,166.9 tons of CO₂ equivalents emitted to the atmosphere per year due to charcoal production and supply in the study area. Thus, the high dependencies of the local community on the charcoal production and supply in the study area have negative effects on Kefa Biosphere reserve forest of Ethiopia and emit huge amount of greenhouse gas (CO₂) into atmosphere. Hence, it is important to develop and implement an eco-friendly strategy that can simultaneously sustain the livelihoods of rural community, energy needs of urban dwellers and forest ecosystem of the region.

Background

Charcoal is a key source of energy and revenue for households in Africa [1, 2]. In 2015, about 3.7 billion m³ of wood extracted from forests worldwide, of which about 1.86 billion m³ (17%) used as fuel either burned directly or converted to charcoal and among the 52 million tons (Mt) of wood charcoal produced globally, over 62% of it produced in Africa [3]. About 50% of the world's population [4], including at least 80% of Africans, relies primarily on charcoal as primary energy source [5].

In sub-Sahara Africa (SSA), over 80% households in urban use charcoal as a main source of cooking energy [6]. Ethiopia was among the top ten charcoal producing countries in the world in 2015 [3]. For example, in 2011 Ethiopia produced about 3.83 Mt of wood charcoal [7]. Moreover, charcoal consumption has been increasing in most developing countries due to an ever-increasing rural to urban migration [7, 8], rising in price of modern sources of energy [9], elevated levels of poverty [10] and its reliability, convenience and accessible for cooking in urban area [11].

Urban areas are the major charcoal consumer and over 80% and 85% of the urban households in sub-Saharan Africa countries [12] and Africa countries [13] respectively consumed charcoal as source of energy. Further, consumption of charcoal predicted to be double in sub-Sahara Africa by 2030, with over 700 million Africans relying on it [14]. Over 0.21 million Mt of charcoal is supplied annually in Ethiopia, of which over 70% of the production is supplied to towns [4].

Charcoal production has enormous contribution for forest degradation and climate change, with four to six-fold larger impacts than wood fuel, due to inefficiency of production process [4]. Further, studies indicated that charcoal making have impact on forest diversity [2] especially on commonly used woody species [15]. It is responsible for the emission of 71.2 Mt of CO₂ and 1.3 Mt of methane in tropics [16].

Alike other part of Ethiopia, firewood and charcoal making are the two most important traditional household energy source in urban household in southwest Ethiopia [17] and the most important causes of deforestation in the region [18, 19]. The livelihood of many rural and urban peoples are dependent on the income from the sale of the charcoal product, yet large scale exploitation of the forest for energy purposes puts an enormous pressure on the ecosystems and have led to environmental degradation and climate change [20, 19]. In this regard, the livelihoods of Manjo community in Sheka and Kefa Zone are highly depends on production and selling of charcoal [21, 19]. Such practices have excessively threatened about 547 ha of Kefa Forest Biosphere reserve located around Bonga town [22]. For example, in SNNP region state, about 6.92 kg/household/day of wood equivalent supply for cooking purposes (1.01 million tons of wood equivalents per annum) with annual deforestation rate of 1.6% (21,866 ha), which representing the highest forest loss rates in the region [23]. Further, estimates showed that demand for biomass energy such as charcoal is expected to be double over the next decades in southwestern part of the country due to lack of alternative energy sources [23]. The upsurge in the charcoal making is mainly at the expense of large-scale harvesting of wood from the nearby forest [17].

Despite, town demand for charcoal and associated forest removal has been increasing over time in the study area, yet, no study has been conducted on the charcoal production and supply, and its impact on environment. Thus, sustainable conservation of the remnant forest of southwest Ethiopia requires knowledge on the amount of charcoal produced from Kefa Biosphere Reserve forests and supply to the town in the region, and the most preferred tree species for charcoal production. Thus, the goal of this study was to quantity the charcoal produced and supplied from Gimbo and Decha districts to Bonga Town, Kefa zone and its associated environmental impacts in southwest Ethiopia.

Materials And Methods

Description of the Study Areas

The study was conducted at Bonga town surrounding Gimbo and Decha districts, Kefa Zone in southwest Ethiopia (Fig. 1). It is located at 450 km southwest of Addis Ababa. The area lies between 70°00'–70°25' and 35°055'–36°037' latitude and longitude. The study area altitude ranges from 1400 to 2028 m a.s.l. The major soil types in the study area are Nitosol, Acrisols, Fluvisols, Luvisols and Vertisols [24]. The annual rainfall pattern is unimodal with a rainy season starts from mid-March to mid-November. Average annual rainfall depth in Bonga (1779 m a.s.l.) is 1707±216 mm/year and annual reference evapo-transpiration depth is 1259 ± 12 mm/year [25]. The average air temperature ranges from 12 to 27°C [26]. The total population of Kefa Zone is 1,152,223, of which 565,902 are men and 586,321 women. The

Bonga town, Decha and Gimbo districts have a total population of 52,910, 165,224 and 121,682 respectively [27].

Sampling and Data Collection Techniques

Sampling Techniques

The study employed both purposive and simple random sampling techniques. Bonga town was selected purposively since the town is the capital of Kefa Zone with the rapid growth of urbanization coupled with large population to which large quantities of charcoal have been supplied. In addition, two peri-urban areas such as Gimbo and Decha districts (where majority of charcoal produced and supplied to Bonga town) selected again purposely based on preliminary survey and key informant interview with wholesalers. Further, five *kebeles* (the smallest administrative unit) were again selected randomly from Gimbo and Decha districts. Thus, Kayi Kela, Keja Araba, Dakiti and Maligawa *kebeles* were selected from Gimbo district, and Shapa *kebele* was selected from Decha district.

Once the *kebeles* were identified, a registered master list of households involved in charcoal production and supply were taken from the kebeles. The four *kebeles*; Kayi Kela, Keja Araba, Dakiti and Maligawa kebeles in Gimbo district have 32, 36, 23, and 27 charcoal producer and supplier households respectively, while the Shapa *kebeles* in Decha district has 30 charcoal producer and supplier households. Thus, the total sample respondent households were determined by using the following formula [28], with 95% confidence level.

$$n = \frac{N}{1 + N(e^2)}$$

Where, n is the number of sample size, N is the total number of household and e is the level of precision (5%). Accordingly, a total of 108 sample households were participated on this study from the five kebeles. To determine the sample size of the kebele, proportional sampling technique was employed. Hence, 24, 26, 17, 19, and 22 households were selected from Kayi Kela, Keja Araba, Dakiti, Maligawa and Shapa kebeles respectively (Table 1).

In addition, purposive sampling was used to select individuals for key informant interview and focus group discussion. Purposive sampling involves selecting a sample based on experiences or knowledge of the desired study [29]. Thus, three key informants per *kebele* from district Agricultural and Natural Resource office, Forest, Environment Protection and Climate Change, and Development Agents (DA), and five key informants of charcoal retailers from Bonga town was selected for an interview. Participant for focus group discussion (FGD) was selected from stakeholder organizations (community elders, youth and women representatives and local kebele administrate). Thus, a total of three FGDs were conducted per kebele and one focus group contains 6 people from different social group.

Table 1

Sample size proportion in the sample Kebeles based on number of charcoal producer and supplier HH in the selected kebeles

Kebeles	Charcoal producer and supplier household	Sampled household	Proportion (%)
Kayi Kela	32	24	22
Keja Araba	36	26	24
Dakiti	23	17	16
Maligawa	27	19	18
Shapa kebeles	30	22	20
Total	148	108	100

Data Collection

Quantitative and qualitative data were collected from household survey, focus group discussion and key informant interview during March-June, 2020. Pre-tested semi-structured questionnaires were used for household survey study. All charcoal producing kilns were properly dated and geocoded using Garmin GPS. Furthermore, the number of trees that were used for charcoal production, and species commonly logged and used for charcoal production were listed and recorded from all the sites with discussion of charcoal producers. The charcoal supply data were collected for 15 consecutive days (15 days*18 h/day = 270 hours) during summer season of the year. Each day was divided into three periods, at 6 hours interval; morning (6:00 a.m–11:59 a.m), afternoon (12:00 p.m–5:59 p.m) and evening (6:00 p.m–11:59 p.m). Those time intervals were selected based on the information collected from key informants and social group leaders. The charcoal supplied to Bonga town through the major inlets was counted and weight recorded, whereby the number of supplied charcoal (in bag) and weight of each supplied charcoal was recorded. Further, the most commonly used wood tree species for charcoal production was first identified during FGD and then the list of species were given to household respondents for ranking and confirmation.

Data Analysis

The data collected was validated to get the relevant data from the study. The validated data was coded for easy classification in order to facilitate tabulation and organization in excel spreadsheet. The types of tree species, number of trees, and total charcoal supply from five sites and mean weights of the different sizes of bags of charcoal and their estimated weights summarized using excel sheet. The tabulated data was then analyzed quantitatively by calculating various percentages.

The ranking the preferences of woody tree species for charcoal by respondents were computed with the principle of weighted average using the ranking index adopted by previous researcher [30] as:

$$Index = \frac{R_n C_1 + R_{n-1} C_2 + \dots + R_1 C_n}{\sum (R_n C_1 + R_{n-1} C_2 + \dots + R_1 C_n)}$$

Where; R_n = value given for the least ranked level (example, if the least rank is 5th, then $R_n = 5$, $R_{n-1} = 4$, $R_1 = 1$, C_n = counts of the least ranked level (in the above example, the count of the 5th rank = C_n , and the count of the 1st rank = C_1).

The amount of carbon emitted to atmosphere due to charcoal production and supply was determined by using the relationship between charcoal and carbon dioxide equivalents. Thus, the contribution of charcoal production to climate change was estimated based on a model developed by different authors [31, 16, 32] as 2.6 kg carbon dioxide equivalent (CO_2e) were emitted per kg of charcoal produced. The number of trees used for producing charcoal was estimated following the methods used by [33] based on the relationship that 1378 kg of charcoal produced from an average of 18 trees of DBH (diameter at breast height) with an average of 32 cm. All the collected data was analyzed using descriptive statistics and SPSS software version 22. The difference in charcoal production and supply among the sites were compared using least significant difference (LSD) at 95% degree of confidence.

Results And Discussions

Results and Discussions

Socio-economic and Demographic Characteristics

Socio-economic and demographic characteristics of households are important determinants of charcoal production and supply behavior [34, 35, 36]. Of the total household respondents, 59.3% and 40.7% of the households were male and female respectively (Table 2). Most (58.3%) of the respondents were in the age between 25–54 years old followed by 15–24 years old (38%). In this regard, about 96.3% of the respondents are under active age groups. Further, majorities (81.5%) of the respondents were married and the remaining are single (8.3%). The education levels of respondents showed that about 77.8% of the respondents were illiterate, while the remaining are primary school completed. Most of the respondents have a family size of 3–4 (41.7%), followed by 5–6 family size (27.8). About 39.8% and 38.9% of the total respondents have less than 1 ha land and landless respectively (Table 2).

Table 2
Socio-economic characteristics of household respondents

Characteristics		Frequency	Percentage (%)
Sex	Male	64	59.3
	Female	44	40.7
Age	15–24	41	38.0
	25–54	63	58.3
	Above 55	4	3.7
Marital status	Married	88	81.5
	Single	9	8.3
	Divorced	6	5.6
	Windowed	5	4.6
Education	Illiterate	84	77.8
	Primary school	24	22.2
Family size	1–2	14	13.0
	3–4	45	41.7
	5–6	30	27.8
	Above 7	19	17.6
Land size	Landless	42	38.9
	< 1 hectare	43	39.8
	1–3 hectare	23	21.3

Charcoal Production

In the study area, the process of charcoal production involves identification of trees species, cutting, sorting of cut trees by their size and diameter, and stack near to the charcoal production site. The wood is then stacked into a pit or heap on a relatively flat plain up to manageable height and covered with a layer of grass/ leaves and soil. In this regard, both female and male members of the households were engaged on both charcoal production and supply activities. In this regard, among the male (64 i.e 100%) and female (44 i.e 100%) respondents were involved in charcoal production. Similarly, all the female respondents were involved in charcoal supply, yet 28% of the male respondents were not involved in charcoal supply (Fig. 2). The absence of males in charcoal supply was due to the charcoal supply by

other female member of the family. Moreover, [37, 38] reported that both man and women are involved in charcoal production.

Despite, charcoal production requires physical strength such as moving and positioning large tree logs, cutting large tree, handling and burning, yet more females from Manjo community are involved in charcoal production. It might be due to low economy, no to small agriculture land and low social status of the Manjo community in the social group. Similarly, [19] reported that Manjo community is socially, economically and culturally marginalized groups. Further, they have weak position in land tenure, and their livelihoods mainly depend on selling of wood and charcoal from the forest in their vicinity. This is common in Sub-Saharan Africa (SSA) where poor peoples are often involved in charcoal production [7].

Charcoal production requires effort to travel long distant, and about 84.7% of the charcoal producers travel > 5 km to reach charcoal production site (Fig. 3A). Since the government prohibits charcoal production and monitor forest in vicinity, going long distance provides free access for preferred tree species removal and freedom for charcoal production. Similarly, [39] reported that charcoal producer travel more than 5 km to find a tree for charcoal production in Somaliland. Further, charcoal production sites in Uganda are 0–5 km far from producer villages [40].

Charcoal production frequency is one of the important indicators for rate of forest degradation in the region. The result showed that about 87% and 9.3% of the respondents produced charcoal seven to nine and four to six times per month respective on each kiln (Fig. 3B). The monthly production cycle is higher than the report by [40] in Uganda, which is two times per month. The high production frequency suggests that more trees were removed from the forest on monthly basis for charcoal production, particularly tree species highly preferred for quality charcoal production was under high pressure in the study area. In this regard, the key informant report showed that the population of tree species preferred for charcoal production was rapidly declining on forest sites around the village. Similarly, [41] reported that rapid tree removal for charcoal production has led to forest degradation and deforestation.

The FGD and key informants report confirmed that charcoal production is increasing from time to time because of the increases of charcoal demand in the town associated with the rapidly growing coffee and tea shops in the roadside of urban and peri-urban areas in Kefa Zone. Moreover, lack of alternative energy sources, frequent power interruption, increasing of human population in the town, accessibility, and easiness for use and transportation are also factor for the continuing production and supply of charcoal in the study area. According to [42], the consumption of charcoal as source of energy determined by various socio-cultural factors like perception, preference, and habit.

The result from the respondents showed that the major drivers for charcoal production in the study areas were lack of agriculture land (40.7%), lack of alternative income source (19.4%), attractive market price (15.7%) and high demand for charcoal (9.3%) (Table 3). Furthermore, the key informant interview results also confirmed that lack of agricultural land, unemployment and poverty, and high price of charcoal driven households to be engaged on charcoal production. Similarly, [33, 13, 7, 43] reported that lack of

land, employment, income source, and poverty are the major driving forces for household participation in charcoal production.

Table 3
Major reasons for household involvement in charcoal production work
in the study areas

Reason for charcoal production	Number of respondents (%)
Lack of alternative income sources	19.4
Poverty	10.2
Lack of agriculture land	40.7
High demands for charcoal (energy)	9.3
Attractive market price for charcoal	15.7
Adopting family practice as culture	4.6

Seasonal variability is one of the determinants for magnitude of charcoal production. The result showed that 68.2% of the respondents reported that charcoal production on the summer (dry season) is higher than winter (wet season) (Fig. 4). This is due to the presence of suitable weather for tree cutting, tree log preparation, carbonization process and transportation during the dry season of the year. Similarly, [35] reported that charcoal production was higher in the dry season compared to wet season in different African countries. While, 28.2% of the respondents reported that no difference in charcoal production volume between dry and wet seasons, and 3.5% of the respondents believed that charcoal production is higher in winter (wet season) (Fig. 4). The FGD result confirmed that higher production during dry season due to comfortable weather during dry season and change of farmers focus to agriculture activity during the wet season.

Charcoal Supply

The results showed that the five inlet sites were significant different ($p < 0.05$) on daily and annual charcoal supplied to Bonga (Table 4). The highest mean daily and annual charcoal supply was recorded at Keyi Kella and Kej Araba inlet sites. On average, 15 tons/day and 5448.8 tons/year of charcoals supplied to Bonga town from five inlet sites of Gimbo and Decha districts (Table 4). The annual charcoal supplied to Bonga was lower than the amount supplied to Addis Ababa city (68, 886 tons/year) [1], to Maputo (Mozambique) (140,000 tons/year), to Dar Es Salaam (Tanzania) (314,000 tons/year) and Lusaka (Zambia) (245,000 tons/year) [44], mainly due to the difference in size of city and population number. Most importantly, the charcoal supplied to Bonga town is at the expense of Kafa Biosphere reserve forests.

On average, a total of 499 bags of charcoal having different bag size (small: 10–25 kg, medium: 26–40 kg, and large: 41–50 kg) supplied to Bonga town every day from the five major inlets sites. Of which, about 140, 168 and 192 charcoal bags were small, medium, and large sized charcoal bags, respectively. The findings was much lower than the reported by [1], a total of 7549 bags of charcoal having different bag size was supplied to Addis Ababa on daily basis. The difference is mainly due to the difference in population, whereby Addis Ababa (capital of Ethiopia), is home for 4.5 millions (2019) people who depends on charcoal as source of energy for household activities. The annual number of different size bags of charcoal (small, medium and large) from Keyi Kella and Kej Araba were significantly different ($p < 0.05$) from Dakiti, Shapa and Melligawa sites. The

highest number of medium and large sized bags of charcoal was recorded at Keyi Kella inlet site, while the highest number of small sized bag of charcoal recorded at Kej Araba inlet site. In general, a total number of 60,728 bags of different bag size of charcoal supplied to Bonga town annually from five inlet sites, of which 16985, 20432, and 23311 bags of supplied charcoals were small, medium and large size, respectively (Table 4).

Table 4
Mean charcoal supply on daily basis to the town through five inlet sits

Charcoal supply by the inlets sites	Mean daily charcoal supply to Bonga town (tons)	Mean annual charcoal supply to Bonga town			
		Charcoal (tons)	Small bag (n)	Medium bag (n)	Large bag (n)
Keyi Kella	$3.54 \pm 0.59a$	$1291.5 \pm 216.5a$	$4550.3 \pm 2168.6a$	$5353.3 \pm 1877.3a$	$7478.4 \pm 1646.4a$
Kej Araba	$3.43 \pm 0.85a$	$1253.3 \pm 313.0a$	$4655.8 \pm 2375.9a$	$4599 \pm 2013.4b$	$5150.6 \pm 2293b$
Dakiti	$2.9 \pm 0.47b$	$1050.7 \pm 172.6b$	$2830.8 \pm 1058.9b$	$3755.4 \pm 1404.2c$	$3885.2 \pm 1577.9c$
Shapa	$2.86 \pm 0.41b$	$1043.0 \pm 150.3b$	$2384.7 \pm 1102.2b$	$3633.8 \pm 971.8cd$	$4088 \pm 1355.9c$
Melligawa	$2.22 \pm 0.44c$	$810.3 \pm 160.9c$	$2563.18 \pm 1137b$	$3090.3 \pm 1446.7d$	$2709.1 \pm 1231.6d$
Over all mean	2.98 ± 0.73	1089.8 ± 269.2	3396.9 ± 1934.1	4086.4 ± 1763.6	4662.3 ± 2304.0
Total	15.0	5448.8	16984.8	20431.78	23311.3

Mean values with similar letter on the column do not have significant difference between them ($p < 0.05$), while mean values with different letter on the column have significant difference between them ($p < 0.05$). n = number.

The annual total number of large sized charcoal bag supplied on the five inlet sites was greater than the number of small and medium sized charcoal bags. Following the large sized bags, the number of medium size charcoal bags was the second supplied to Bonga town (Fig. 5). According to [1] report, high number of medium sized bags followed by small bag sized charcoal supplied annually to Addis Ababa city. The number of medium sized bags (1,637,792) reported by [1] was higher than the number of large sized (69,934) and medium sized (61,296) charcoal bags supplied from five inlets to Bonga town.

More than 90% of the respondents reported that the major means of transportation of charcoal to the closest Bonga town marketplace was through human labor. While the remaining respondents were reported donkey as second means of charcoal transportation. In this regard, females play the major role of supply and selling of charcoal to the marketplace and in return, they buy important basic household items from the market.

In Ethiopia, charcoal produced from state-owned forests and woodlands, charcoal making is illegal. Thus, charcoal transportation and supply is determined by time of the day in the study area. The survey results revealed that there is a significant variation on the inflow of charcoal supplied to the town at different times of a day (morning, afternoon, and evening). The mean charcoal supply in the morning and afternoon time are significantly higher than ($p < 0.05$) from the evening (Table 5). However, no significant difference in charcoal supply observed between morning and afternoon. Similarly, the total daily charcoal supply from all the five inlet sites on the morning time (5.7 tons) and afternoon time (5.3 tons) are higher than evening (3.9 tons) (Table 5). The highest supply in the morning and afternoon may be associated with the supplier interest to have more time to purchases different household items from the town and to have enough time to go back to their home. Since it is illegal to openly supply and transport charcoal in the morning and afternoon time on the town, they hide the charcoal from police and local patrols by different covering materials like false banana leaf and polypropylene sack. The key informant and FGD also confirmed that most of charcoals come to the town during morning and afternoon than at evening. Our finding is in line with [45] reported that, higher proportion of charcoal supplied in the morning than other time of the day.

Table 5
Daily charcoal supply at different time intervals from five inlet sites of Bonga town

Charcoal supply inlets	Charcoal supplied (ton/day)		
	Morning	Afternoon	Evening
Keyi Kella	1.43	1.16	0.92
Kej Araba	1.45	1.20	0.79
Dakiti	1.03	1.08	0.80
Shapa	1.04	1.05	0.75
Melligawa	0.80	0.79	0.63
Over all mean (tons/day)	1.15 ± 0.28a	1.05 ± 0.16a	0.78 ± 0.1b
Total (ton/day)	5.7	5.3	3.9

Mean values with similar letter on the column do not have significant difference between them ($p < 0.05$), while mean values with different letter on the column have significant difference between them ($p < 0.05$).

Environmental implications of charcoal production and supply

Implications On Forest Resources

The wood tree species from where the charcoal produced determines the market price of the charcoal and charcoal burning efficiency. According to the respondents, the major eight most preferred tree species for charcoal production in ranks are *Millettia ferruginea* (Hochst.) Baker, *Ehretum cymosa* Thonn, *Vepris dainellii* (Pichi. -Serm.) Kok., *Trichilia dregeana* Sond, *Allophylus abyissinica* (Hochst.) Radlk, *Rothmania urcelliformis* (Hiern) Robyns, *Dombeya torrida* (J.F.Gmel.) Bamps and *Maesa lanceolata* Forssk respectively (Table 6). This implies that, the tree species on the top ranks are the one with highest preference by the household because of their burning efficiency and low ash contents.

However, selective cutting of those preferred species for charcoal production might have led to significant decline and extinction of those indigenous species from the region. For example, *Millettia ferruginea* and *Vepris dainellii* is one of the endemic and multipurpose plant species in Ethiopia, that requires effective conservation as one prior species of the global biodiversity. Similarly, [46] reported a significant decline of 18 different preferred species from forest due to charcoal production in Nigeria, Burkina Faso, Mali, Niger and Senegal. Selective use practices are the major causes for 11–20% deforestation in developing countries [47]. Similarly, [48] reported that selective use of *Swietenia macrophylla* King in Ghana by 80% of the households in two villages have led to extinction of the species. Furthermore, removing most

preferred species and leaving woodlands of lower quality are the principal cause of deforestation in some African country like Tanzania [49].

Table 6
Ranking index of wood tree species preference for charcoal production by charcoal producers

Preferred species	Rank								weight	%	Rank
	1	2	3	4	5	6	7	8			
<i>Millettia ferruginea</i> (Hochst.) Baker	27	15	8	10	17	2	5	1	504	14.9	1
<i>Ehretum cymosa</i> Thonn.	13	20	27	3	9	8			481	14.2	2
<i>Veprisdainellii</i> (Pichi. -Serm.) Kok.	17	13	8	22	12	0	6		445	13.1	3
<i>Trichilia dregeana</i> Sond	20	7	15	8	13	5	12	4	434	12.8	4
<i>Allophylus abyissinica</i> (Hochst.) Radlk	10	12	17	17	9	10	4	6	431	12.7	5
<i>Rothmania urcelliformis</i> (Hiern) Robyns	5	10	11	6	23	18	7		366	10.8	6
<i>Dombeya torrida</i> (J.F.Gmel.) Bamps	3	9	17	15	16	11	0	2	363	10.7	7
<i>Maesa lanceolata</i> Forssk.	0	7	19	20	11	10	8	6	359	10.6	8

The key informants and FGD confirmed that *Millettia ferruginea*, *Ehretum cymosa*, *Vepris dainellii*, *Trichilia dregeana*, *Allophylus abyissinica*, *Rothmania urcelliformis*, *Linoviera latipetela* and *Maesa lanceolata* were the major preferred tree species because of high calorific value and burning efficiency. Thus, charcoal produced from those species were highly demanded by households in the town and sold by better price. Further, the field observation on Keja Araba kebele also confirmed that large number of preferred species cutting remnants and low population of preferred tree species like *Millettia ferruginea* around charcoal production sites. Besides, charcoal production methods using traditional kiln were also inefficient and thereby demands high tree per production cycle.

According to [50], 63 m³ of green wood provides about 0.20 tons of charcoal and equal volume (63 m³) of dried wood gives about 0.23 tons of charcoal processed in the traditional earth kilns. In this regard, to produce an annual charcoal of 5448.8 tons in the study area, it requires about 1,716,372 m³ of green wood and 1,492,497.4 m³ of dry wood from the forest in the production sites. Further, [33] reported that an average of 18 trees having diameter at breast height of 32 cm required to produce 1.38 tons of charcoal, and in this regard to produce an annual charcoal of 5448.8 tons, it requires a removal of 71,071 trees from the Kefa Biosphere Reserve forest per year. [1] reported that to satisfy the charcoal demand of Addis Ababa city, about 899,818 trees were removed from the surrounding forest on yearly basis. This is

the worst scenario of the forest removal and biodiversity loss emanates from the removal of specific preferred trees species for charcoal production.

Implications On Atmospheric Carbon Emission

Charcoal production and supply have contributed its part in emission of carbon dioxide in to the atmosphere. Model developed by different studies [31, 16, 32] indicated that, 0.001 tons of charcoal production can emit 0.0026 tons of CO₂ equivalent (CO₂e). Thus, to produce an annual charcoal of 5448.8 tons supplied to Bonga town, a total of 14,166.9 tons of CO₂ equivalents emitted to the atmosphere per year from charcoal production sites of the study area. Similarly, [32] reported that 1,554,699 tons CO₂e were emitted to atmosphere per year due to traditional charcoal production technique in Kampala, which is higher than the CO₂e emission from the charcoal production sites of the study area. Charcoal production and burning is among the important environmental degrading practices, as they emit carbon monoxide, hydrocarbons and particulate matters toxic to the atmosphere, which are all concerns to human health beyond their negative effects on the environment [1].

Conclusion

Charcoal production and supply are the sources of livelihood for millions of people in developing countries. In Kefa zone, southwest Ethiopia, both men and women participated in charcoal production and supply activities. Charcoal production and supply to Bonga town at the expense of Kefa Biosphere reserve forest have led to forest degradation. Most importantly, the increasing demand for charcoal produced from particular preferred tree species have led to decreases in the number of preferred species in the forest. Among the top three preferred tree species for charcoal are *Millettia ferruginea* (Hochst.) Baker, *Ehretum cymosa* Thonn. *Vepris dainellii* (Pichi. -Serm.) Kok, of which two, *Millettia ferruginea* and *Vepris dainellii*, are endemic and multipurpose tree species of Ethiopia, that require effective in-situ conservation. Further, charcoal production has led to an increase in greenhouse gas emission (CO₂ emission).

Thus, the high dependency of the local community on charcoal production and supply in the study area, have negative effects on Kefa Biosphere Reserve forest species diversity and local climate. Hence, it is important to develop and implement an eco-friendly strategy that can simultaneously sustain the livelihoods of the rural community, forest ecosystem and energy needs of urban dwellers.

Abbreviations

CSA: Central Statistics Agency; CO₂e: CO₂ equivalent; FAO: Food and Agricultural Organization; FGD: Focal Group Discussion; GHG: Green House Gas; MT: Metric Tons; NMA: National metrology agency; SAS: Statistical Analysis Software; SNNPR: Southern Nations, Nationalities and People of Region; SPSS: Statistical Package for Social Science; SSA: Sub-Saharan Africa.

Declarations

Ethical Approval and Consent to participate: Not applicable

Consent for publication: Not applicable

Availability of support data: all the data's are available on the tables.

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Authors' contributions

-Temesgen Gebremeskel: Conceptualization, Methodology, Investigation, Data curation, Validation, Writing-Original draft preparation.

-Henok Kassa: involves in methodology, data curation, investigation, validation, writing-reviewing and language editing. All authors read and approved the final manuscript

-Kassahun Mutatu: involves in methodology, data curation, investigation, validation, writing-reviewing and language editing. All authors read and approved the final manuscript

-Ephrem Chekole: involves in validation, writing-reviewing and language editing. All authors read and approved the final manuscript

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References

1. Alem, S., Duraisamy, J., Legesse, E., Seboka, Y. and Mitiku, E. 2010. Wood charcoal supply to Addis Ababa City and its effect on the environment. *Energy & environment*, 21(6), pp.601-609. <https://doi.org/10.1260/0958-305X.21.6.601>
2. Kiruki, H.M., van der Zanden, E.H., Kariuki, P. and Verburg, P.H. 2020. The contribution of charcoal production to rural livelihoods in a semi-arid area in Kenya. *Environment, Development And Sustainability*, 22(7), pp.6931-6960. <https://doi.org/10.1007/s10668-019-00521-2>
3. FAO. 2016. FAOSTAT, Global Food and Agriculture data Available online at: http://faostat.fao.org/Portals/_faostat/documents/pdf/wood%20charcoal.pdf. Accessed on Jan

10/2020.

4. Kammen, D.M. and Lew, D.J. 2005. Review of Technologies for the Production and Use of Charcoal. Renewable and appropriate energy laboratory report, 1.
5. Kituyi, E. 2002. Towards sustainable charcoal production and use: A systems approach. Business.
6. Neufeldt, H., Fuller, J. and Langford, K. 2015. From transition fuel to viable energy source: improving sustainability in the sub-Saharan charcoal sector. Nairobi: World Agroforestry Centre. DOI: <http://dx.doi.org/10.5716/WP15011>
7. Bekele, M. and Girmay, Z. 2014, June. Reading through the charcoal industry in Ethiopia: production, marketing, consumption and impact. Forum for Social Studies.
8. Dam, J.V. 2017. The charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods. The charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods.
9. Bekele, M., Zewdie, S., Boissière, M. and Atmadja, S. 2019. REDD+ MRV implementation in Ethiopia: Review of the context, framework and progress.
10. Streck, C. and Zurek, M. 2013. Addressing Agricultural Drivers of Deforestation. Opportunities for catalytic donor intervention, ClimateFocus.
11. Borokini, T.I. and Babalola, F.D. 2012. Management of invasive plant species in Nigeria through economic exploitation: lessons from other countries. Management of Biological Invasions, 3(1), p.45.
12. Zulu, L.C. and Richardson, R.B. 2013. Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa. Energy for Sustainable Development, 17(2), pp.127-137. <https://doi.org/10.1016/j.esd.2012.07.007>
13. Nyembe, M. 2011. An econometric analysis of factors determining charcoal consumption by urban households. Master's thesis, Environmental Economics and Management, Swedish University of Agricultural Sciences.
14. Kappel, R.T. and Ishengoma, E.K. 2006. Economic growth and poverty: does formalization of informal enterprises matter?
15. Kouami, K., Yaovi, N. and Honan, A. 2009. Impact of charcoal production on woody plant species in West Africa: A case study in Togo. Scientific Research and Essays, 4(9), pp.881-893. <https://doi.org/10.5897/SRE.9000566>
16. Chidumayo, E.N. and Gumbo, D.J. 2013. The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. Energy for Sustainable Development, 17(2), pp.86-94. <https://doi.org/10.1016/j.esd.2012.07.004>
17. Tadesse, W. 2007. The impacts of land use/land cover changes on biodiversity in Masha and Anderacha Woredas of Sheka Zone, SNNP Regional State. Forests of Sheka: Ecological, Social, Legal and Economic Dimensions of Recent Land Use/Land Cover Changes, Overview and Synthesis. Multidisciplinary Case Studies on Impact of Landuse/Land-Cover Changes, Southwest Ethiopia, pp.57-89.

18. Tadesse, G., Zavaleta, E., Shennan, C. and FitzSimmons, M. 2014. Prospects for forest-based ecosystem services in forest-coffee mosaics as forest loss continues in southwestern Ethiopia. *Applied Geography*, 50, pp.144-151. <https://doi.org/10.1016/j.apgeog.2014.03.004>.
19. Kassa, H., Dondeyne, S., Poesen, J., Frankl, A. and Nyssen, J. 2017. Transition from forest-based to cereal-based agricultural systems: A review of the drivers of land use change and degradation in Southwest Ethiopia. *Land Degradation & Development*, 28(2), pp.431-449. <https://doi.org/10.1002/ldr.2575>
20. Amede, T., Belachew, T. and Geta, E. 2001. Reversing degradation of arable lands in Southern Ethiopia. *Managing African Soils*, (23).
21. Zewdie J. 2007. The impact of cultural changes on the people of Sheka and their traditional resource management practices: in the case of Masha Woreda, Sheka Zone. A clue for advocacy and informed decision making. In *Forests of Sheka: multidisciplinary case studies on impact of LULCC, southwest Ethiopia*, M Fetene (ed). MELCA Mahiber: Addis Ababa; 58– 89.
22. Nune, S. 2008. Flora biodiversity assessment in Bonga, Boginda and Mankira forest, Kafa, Ethiopia. Addis Ababa, Ethiopia, Ethiopian Wildlife and Natural History Society.
23. Yurnaidi, Z. and Kim, S. 2018. Reducing biomass utilization in the Ethiopia energy system: A national modeling analysis. *Energies*, 11(7), p.1745. <https://doi.org/10.3390/en11071745>
24. Dewitte, O., Jones, A., Spaargaren, O., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Gallali, T., Hallett, S., Jones, R., Kilasara, M. 2013. Harmonisation of the soil map of Africa at the continental scale. *Geoderma* 211, 138–153. <https://doi.org/10.1016/j.geoderma.2013.07.007>
25. NMA. 2013. Ethiopia meteorology station 30-year rainfall data. New merged 30-year climate time series. National Meteorology Agency: Addis Ababa.
26. Tadesse, M., Alemu, B., Bekele, G., Tebikew, T., Chamberlin, J., Benson, T. 2006. *Atlas of the Ethiopian Rural Economy*, first ed. CSA and IFPRI, Addis Ababa.
27. CSA. 2019. Ethiopia population data 2019 projection based on the 2007 Census. Addis Ababa: Central Statistical Agency.
28. Yemane, M. 1967. *Elementary Sampling Theory*, Printice-Hall Inc. Englewood Cliffs, New Jersey, USA.
29. Cresswell, J. W., and Plano Clark, V. L. 2011. *Designing and conducting mixed method research* (2nd ed.). Thousand Oaks, CA: Sage.
30. Musa, L.M.A., Peters, K.J. and Ahmed, M.K.A. 2006. On farm characterization of Butana and Kenana cattle breed production systems in Sudan. *Livestock research for rural development*, 18(12), pp.1-15.
31. Pennise, D.M., Smith, K.R., Kithinji, J.P., Rezende, M.E., Raad, T.J., Zhang, J. and Fan, C. 2001. Emissions of greenhouse gases and other airborne pollutants from charcoal making in Kenya and Brazil. *Journal of Geophysical Research: Atmospheres*, 106(D20), pp.24143-24155. <https://doi.org/10.1029/2000JD000041>
32. Ekeh, O., Fangmeier, A. and Müller, J. 2014. Quantifying greenhouse gases from the production, transportation and utilization of charcoal in developing countries: a case study of Kampala, Uganda.

- The International Journal of Life Cycle Assessment, 19(9), pp.1643-1652.
<https://doi.org/10.1007/s11367-014-0765-7>
33. Malimbwi, R.E. and Zahabu, E.M., 2008. Woodlands and the charcoal trade: the case of Dar es Salaam City. Research and development for sustainable management of semiarid miombo woodlands in East Africa. Working Paper, (98), pp.93-114.
 34. Isah, A.D., Shamaki, S.B., Adamu, Y., muhammed Shehu, A., Umar, L.A. and Muhammad, M. 2021. Survey of Species Preference and Method of Charcoal Production in Kaduna, Nigeria.
 35. Nyarko, I., Nwaogu, C., Miroslav, H. and Peseu, P.O. 2021. Socio-Economic analysis of wood charcoal production as a significant output of forest bioeconomy in Africa. *Forests*, 12(5), p.568.
<https://doi.org/10.3390/f12050568>
 36. Tassie, K., Misganaw, B., Addisu, S. and Tesfaye, E. 2021. Socioeconomic and Environmental Impacts of Charcoal Production Activities of Rural Households in Mecha District, Ethiopia. *Advances in Agriculture*, 2021. <https://doi.org/10.1155/2021/6612720>
 37. Delahunty-Pike, A. 2012. Gender equity, charcoal and the value chain in Western Kenya.
 38. Jones, D., Ryan, C.M. and Fisher, J. 2016. Charcoal as a diversification strategy: the flexible role of charcoal production in the livelihoods of smallholders in central Mozambique. *Energy for Sustainable Development*, 32, pp.14-21. <https://doi.org/10.1016/j.esd.2016.02.009>
 39. Candlelight. 2012. "The Charcoal sector Oodweyne region–somaliland", Candlelight for health, education, and environment.
 40. Khundi, F., Jagger, P., Shively, G. and Sserunkuuma, D. 2011. Income, poverty and charcoal production in Uganda. *Forest Policy and Economics*, 13(3), pp.199-205.
<https://doi.org/10.1016/j.forpol.2010.11.002>
 41. Kutsch, W.L., Merbold, L., Ziegler, W., Mukelabai, M.M., Muchinda, M., Kolle, O. and Scholes, R.J. 2011. The charcoal trap: Miombo forests and the energy needs of people. *Carbon balance and management*, 6(1), pp.1-11. <https://doi.org/10.1186/1750-0680-6-5>
 42. Mugo, F. and Ong, C. 2006. Lessons from eastern Africa's unsustainable charcoal business.
 43. Brobbey, L.K., Pouliot, M., Hansen, C.P. and Kyereh, B. 2019. Factors influencing participation and income from charcoal production and trade in Ghana. *Energy for Sustainable Development*, 50, pp.69-81.
 44. Msuya, N., Masanya, E. and Temu, A.K. 2011. Environmental burden of charcoal production and use in Dar es Salaam, Tanzania. doi:10.4236/jep.2011.210158
 45. Zahabu, E. and Malimbwi, R.E. 2012. The potential of community forest management under REDD+ for achieving MDG goals in Tanzania. In *Community Forest Monitoring for the Carbon Market* (pp. 154-167). Routledge.
 46. Kindt, R., Kalinganire, A., Larwanou, M., Belem, M., Dakouo, J.M., Bayala, J. and Kairé, M. 2008. Species accumulation within land use and tree diameter categories in Burkina Faso, Mali, Niger and Senegal. *Biodiversity and conservation*, 17(8), pp.1883-1905. <https://doi.org/10.1007/s10531-008-9326-3>

47. Moses, P.A.U.L.O. 2017. Charcoal production and its implications on sustainability of community-based forest management. A case of Mbangala village land forest reserve, Songwe district (Doctoral dissertation, Sokoine University of Agriculture).
48. Pabi, O. and Morgan, E.A. 2002. Land-cover change in the northern forest-savanna transition of Ghana.
49. Van Beukering, P., Kahyarara, G., Massey, E., di Prima, S., Hess, S., Makundi, V. and Van der Leeuw, K. 2007. Optimization of the charcoal chain in Tanzania. Institute for Environmental Studies, Amsterdam, pp.2007-2003.
50. Nigatu, G., Bekele, T. and Fantu, W. 2012. Impact of Moisture Content and Mound Size on Recovery and Quality of Charcoal from *Prosopis juliflora* (SW.) DC. in Rift Valley of Ethiopia. The African Journal of Plant Science and Biotechnology.

Figures

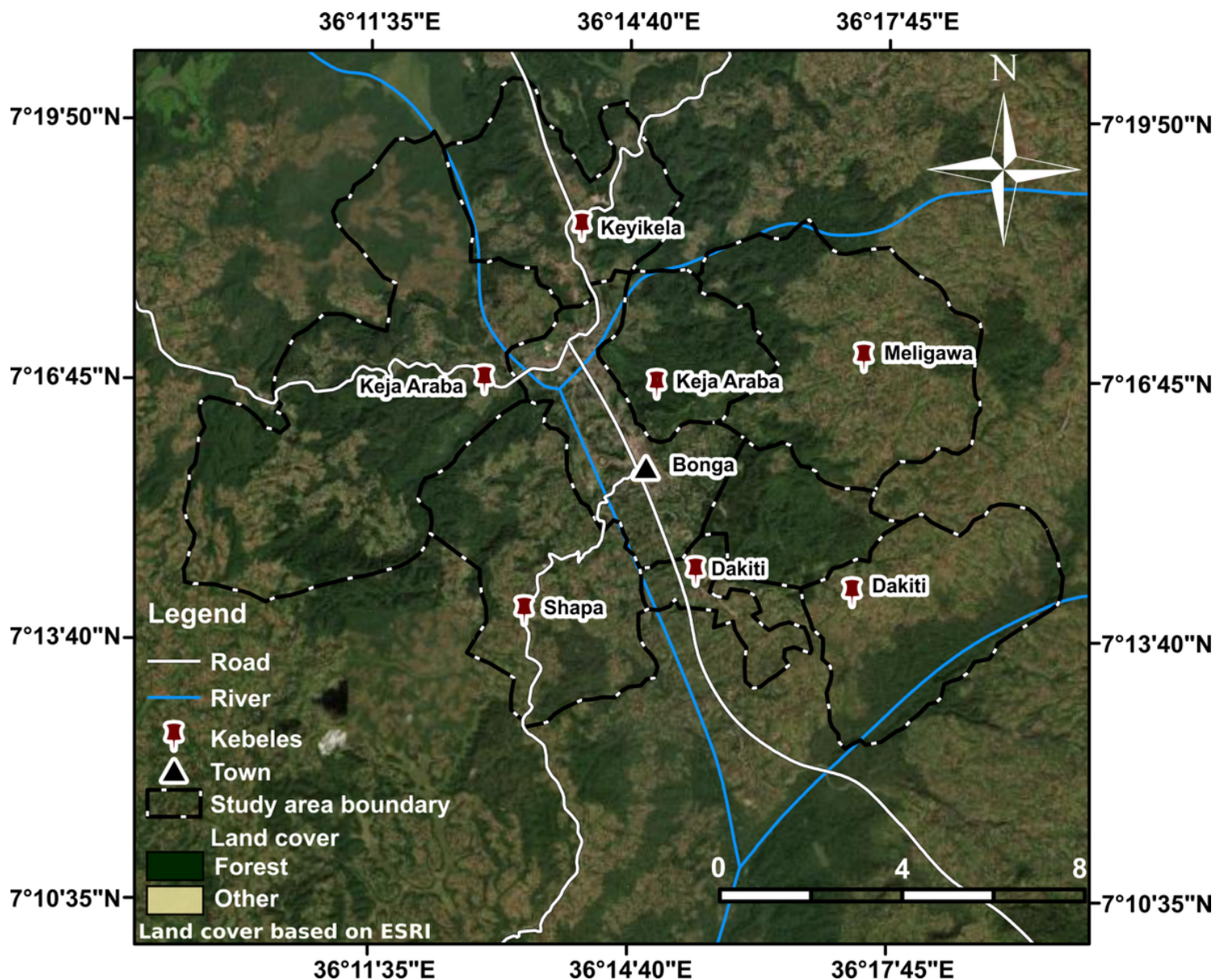


Figure 1

Map of the study area showing the location of studied *kebeles*. Base map source from ESRI image.

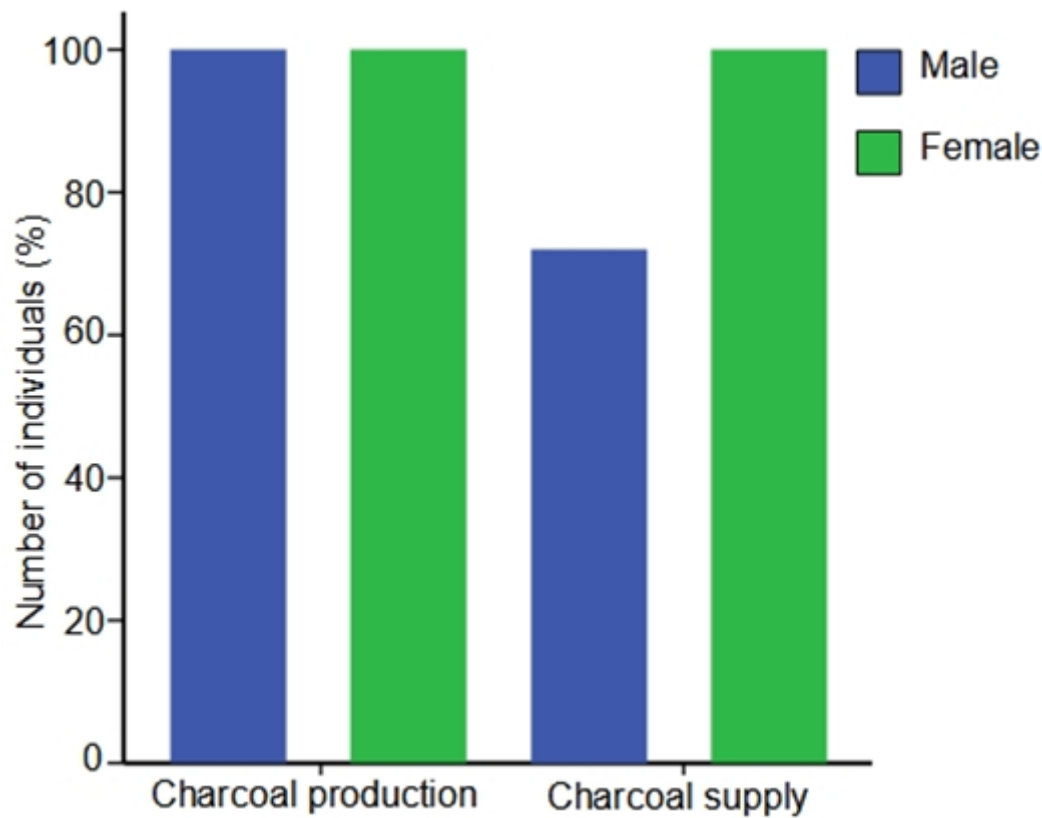


Figure 2

Household participation in charcoal production and supply

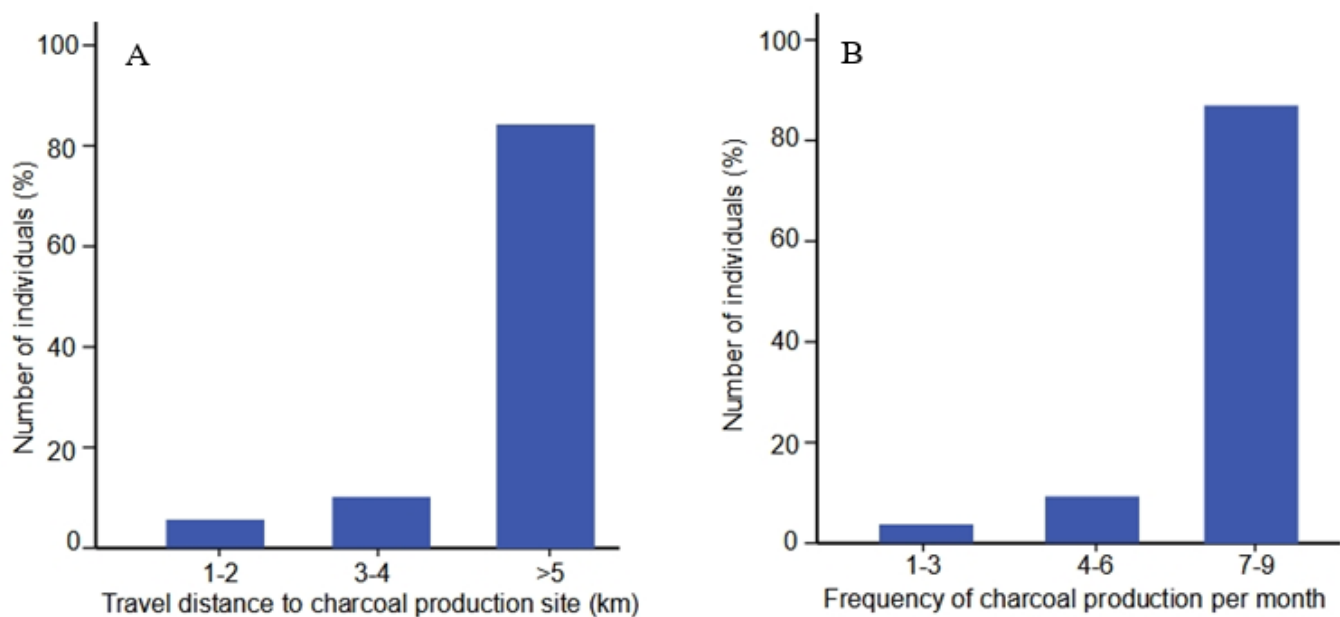


Figure 3

Distance travel to charcoal producer site (km) (A) and number of charcoal production on kiln per month (B)

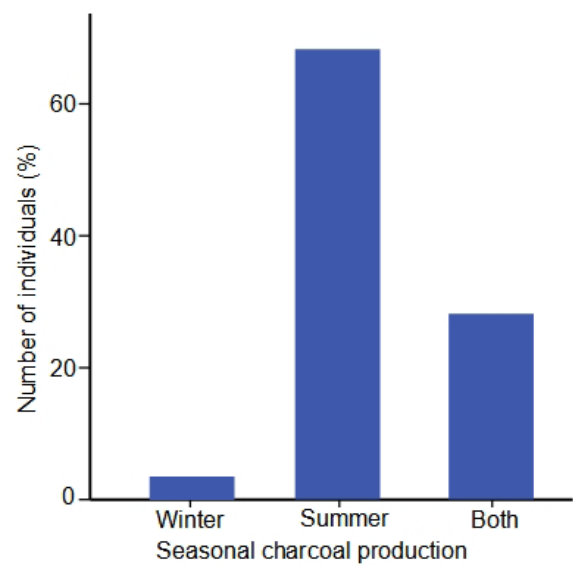


Figure 4

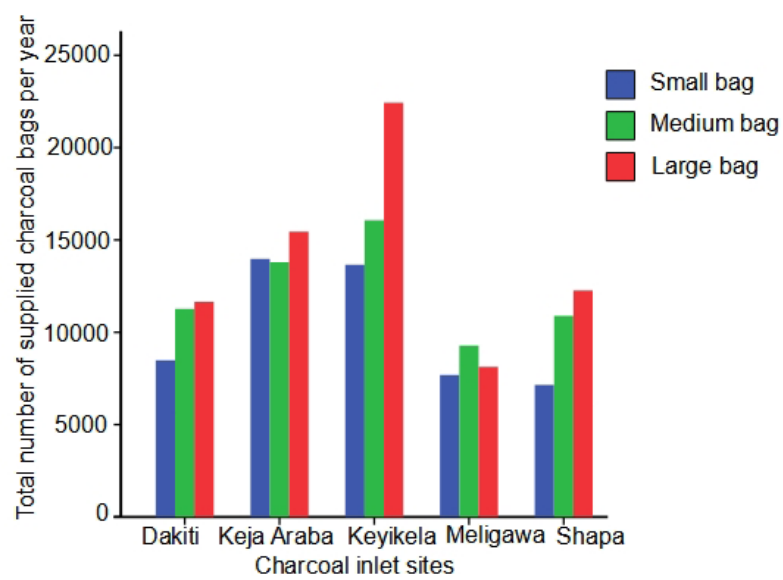


Figure 5

Annual total number of charcoal supplied to Bonga town